DEMONSTRATION REPORT

Quality Control Methodologies for Advanced EMI Sensor Data Acquisition and Anomaly Classification – Former Southwestern Proving Ground, Arkansas

ESTCP Project MR-201231

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14. ABSTRACT

This report details a live site demonstration project conducted by WESTON at the former Southwestern Proving Ground (SWPG) as part of Environmental Security Technology Certification Program (ESTCP) Munitions Response Project MR-201231. The purpose of the project was to demonstrate the effectiveness of the advanced sensor and classification methodology for identifying targets of interest (TOIs) at a site containing a diversity of munitions in high concentrations. A total of 11.23 acres of dynamic surveys were conducted using MetalMapper advanced electromagnetic induction (EMI) sensor. A total of 2,116 targets were selected from the dynamic data for cued investigation, and 1,398 targets were intrusively investigated. The classification methodology resulted in the correct classification of 100% of TOI and yielded a reduction in clutter digs of 83%.

15. SUBJECT TERMS

MetalMapper, UXO, MEC, SWPG, geophysical classification, FUDS, MMRP, ESTCP

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LIST OF ACRONYMS

%	percent
µT	micro Tesla
cm	centimeter
DGM	digital geophysical mapping
DSB	Defense Science Board
EE/CA	Engineering Evaluation/Cost Analysis
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	global positioning system
IDA	Institute for Defense Analysis
IMU	inertial measurement unit
ISO	Industry Standard Object
IVS	instrument verification strip
m^2	square meter
MD	munitions debris
MDAS	material documented as safe
MEC	munitions and explosives of concern
mm	millimeter
MR	munitions response
MRS	Munitions Response Site
PDA	personal data assistant
PVC	polyvinyl chloride
RF	Recovery Field
RMS	root mean square
ROC	receiver operating characteristic
RTK	Real Time Kinematic
QC	quality control
SERDP	Strategic Environmental Research and Development Program
SUXOS	Senior Unexploded Ordnance Supervisor
SWPG	Southwestern Proving Ground
TOI	target of interest
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UXOQCS/SO	Unexploded Ordnance Quality Control Specialist/Safety Officer
UXO	unexploded ordnance
WESTON®	Weston Solutions, Inc.
WWII	World War II

EXECUTIVE SUMMARY

Weston Solutions, Inc. (WESTON®) performed a live site demonstration project using the Geometrics MetalMapper advanced electromagnetic induction (EMI) sensor at the former Southwestern Proving Ground (SWPG) as part of Environmental Security Technology Certification Program (ESTCP) Munitions Response Project MR-201231. The demonstration was designed to demonstrate the effectiveness of the advanced sensor and classification methodology at a site containing a diversity of munitions in high concentrations.

The primary objectives of the Live Site Demonstration Advanced Classification Activities were to do the following:

- Correctly classify all targets of interest (TOIs).
- Correctly identify TOI and non-TOI sizes.
- Correctly estimate extrinsic parameters (measured location and depths of items).
- Reduce clutter digs by at least 50%.
- Extract reliable parameters for at least 95% of cued anomalies.

WESTON conducted the field demonstration in three phases with 4 to 6 weeks between each phase to perform data processing and classification. The initial phase included site setup, surface sweep, production area seeding, and dynamic data collection of the survey area in RF-15. A total of 43 seeds were installed, and 11.23 acres of dynamic surveys were conducted with the MetalMapper. A total of 2,116 targets were selected from the dynamic data for cued investigation, which was performed during the second phase. WESTON returned to SWPG for the final intrusive phase, during which 1,398 targets were intrusively investigated.

The MetalMapper is an advanced EMI system developed by Geometrics, Inc., with support from ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven triaxial receiver antennas inside the Z (bottom) loop, allowing 21 independent measurements of the transient secondary magnetic field. Dynamic data were collected using only the Z transmit loop and the seven receivers, although only the responses measured by the Z loop on the center five receivers were used in calculating the dynamic response.

Cued data were collected using all three transmitters and 21 receiver loops. The collected data were inverted and analyzed using the UX-Analyze Advanced module in Geosoft Oasis montaj. Once analysis was complete, a ranked dig list was submitted for the site containing predicted anomaly locations for use in the subsequent intrusive investigation. The intrusive investigation, which was performed following the submittal of the ranked dig list, included two stages: the investigation of the 504 targets identified in the dynamic data set within a defined area regardless of the classification decision and the investigation of another 134 targets classified as digs outside this area.

The classification methodology resulted in the correct classification of 100 percent (%) of TOI, and yielded a reduction in clutter digs of 83%. The sizes of 97% of the anomalies selected for intrusive investigation were accurately predicted from the analyzed cued data. Extrinsic parameters estimated for the anomalies (predicted x, y, and z locations) were compared to the actual intrusive results. Only 67% of the predicted locations were within 15 centimeters (cm) of

the actual measured location, and 75% of the predicted depths were within 10 cm of the actual depths. The large percentage of item locations that were not predicted correctly is most likely due to the high anomaly density within the demonstration area, which often resulted in multiple small items beneath the sensor footprint at each cued data point. Approximately 97% of the digs resulted in small pieces of frag, which were either too numerous or too small to model well, thus yielding poor fit locations.

1. INTRODUCTION

This is one of a series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for munitions response (MR). This demonstration is designed to evaluate the classification methodology at a site with a diversity of munitions types (20 millimeter (mm) to 155mm projectiles). The MetalMapper was demonstrated at the former Southwestern Proving Ground (SWPG) in both dynamic and cued mode by Weston Solutions, Inc. (WESTON®).

1.1 BACKGROUND

The Military Munitions Response Program (MMRP) is constrained by available resources. Remediation of the entire inventory using current practices is cost prohibitive within current and anticipated funding levels. With current planning, estimated completion dates for munitions response on many sites are decades away. The Defense Science Board (DSB) observed in its 2003 report that significant cost savings could be realized if successful classification and differentiation between munitions and other sources of anomalies could be implemented. If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of Munitions Response Sites (MRSs) that are currently forecast to be untouched for decades.

To build on the success of previous studies and address resource issues, ESTCP funded a demonstration of the MetalMapper instrument at SWPG. SWPG was selected as a demonstration site because it contains a wide range of World War II (WWII)-related targets of interest (TOIs).

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of the demonstration was to validate classification technology at the former SWPG. WESTON performed the following tasks to achieve this overall objective:

- Installed an instrument verification strip (IVS) at Recovery Field (RF)-15.
- Performed dynamic digital geophysical mapping (DGM) using the Geometrics MetalMapper in a subset of RF-15.
- Performed static, cued target interrogation using the MetalMapper in RF-15.
- Processed dynamic and static geophysical data to correctly classify the TOI.
- Performed reacquisition and intrusive investigation of targets selected for cued interrogation.

Dynamic DGM data were collected from 11.23 acres at RF-15 with the MetalMapper system. WESTON evaluated the dynamic MetalMapper data and selected approximately 26,000 targets based on anomaly selection thresholds derived from the IVS and dynamic test data.

WESTON then collected static cued data using the MetalMapper to evaluate its performance in classifying anomalies. Of the approximately 26,000 anomalies detected in RF-15, 2,116 were reacquired for cued interrogation with the MetalMapper. WESTON intrusively investigated 1,398 of the targets that were cued. Based on the classification results, a prioritized dig list was submitted to ESTCP for performance scoring.

1.3 REGULATORY DRIVERS

The MMRP is charged with characterizing and, where necessary, remediating MRSs. When an MRS is remediated, it is typically mapped with a geophysical system, based on either a magnetometer or an advanced electromagnetic induction (EMI) sensor, and the locations of all detectable signals are excavated. Many of these detections do not correspond to munitions, but rather to harmless metallic objects or geologic features. Field experience indicates that often in excess of 90% of objects excavated during the course of a munitions response are found to be nonhazardous items. Current geophysical technology, as it is traditionally implemented, does not provide a physics-based, quantitative, validated means to discriminate between hazardous munitions and nonhazardous items.

With no information to suggest the origin of the signals, all anomalies are currently treated as though they are intact munitions when they are dug. They are carefully excavated by unexploded ordnance (UXO) technicians using a process that often requires expensive safety measures, such as barriers or exclusion zones. As a result, most of the costs to remediate an MRS are currently spent on excavating targets that pose no threat. If these items could be determined with high confidence to be nonhazardous, some of these expensive measures could be eliminated or the items could be left unexcavated entirely.

2. TECHNOLOGY

This demonstration consisted of dynamic and cued data collection with the MetalMapper advanced geophysical sensor system. Analysis of the data was performed using conventional and advanced data processing methods to select anomalies from the advanced sensor dynamic data and then extract features and perform anomaly classification on the advanced sensor cued data.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Geometrics MetalMapper

The Geometrics MetalMapper is the first commercially available advanced EMI sensor designed to enable classification of TOI. It consists of three orthogonal 1-square meter (m^2) transmit coils and seven 10-centimeter (cm), three-component, orthogonal receiver coils (Figure 2-1). The system was proven at the ESTCP live demonstration at the former Camp San Luis Obispo and other live sites to be effective at discriminating between munitions and non-munitions items. WESTON operated the MetalMapper in both dynamic detection and cued interrogation modes during the live-site demonstration at former SWPG. Dynamic MetalMapper data were processed using Geosoft Oasis montaj software with the UX-Detect module. The MetalMapper has not been used to collect dynamic DGM data at many sites; however, it provides more accurate target positioning advantages over currently used technologies (e.g., M61-MK2) because of its seven three-component receivers, greater data density, and improved positioning electronics.

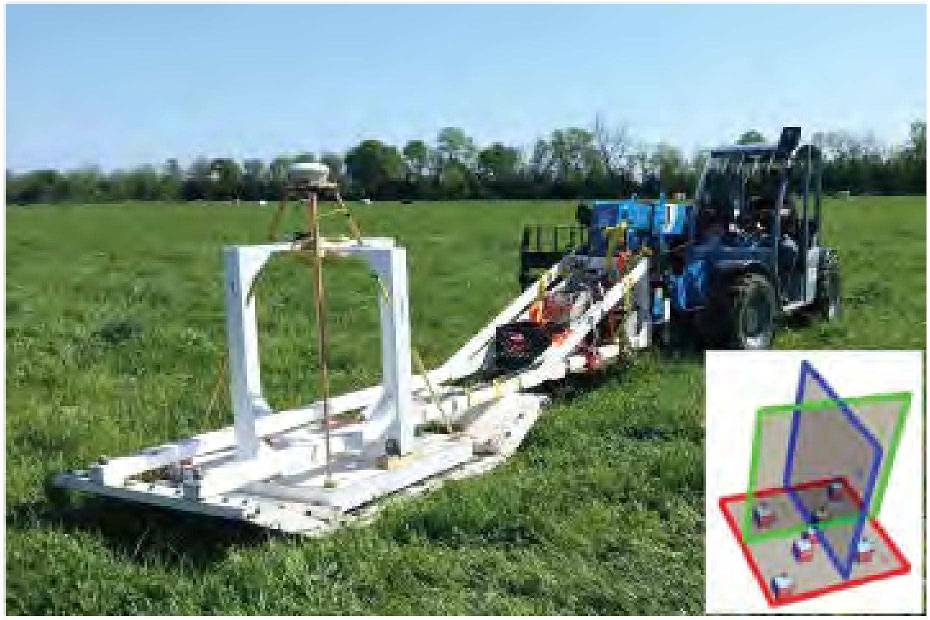
WESTON collected dynamic data from 11.23 acres at RF-15 and performed cued interrogation with MetalMapper on 2,116 targets. The static cued data were processed using Geosoft Oasis montaj software, Advanced UX-Analyze module to extract the three principal axis polarizability curves for each target. Cued target data were then analyzed and subsequently matched to a library of polarizability curves to classify the target as either TOI or non-TOI.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The major advantage of the advanced EMI sensor and the UX-Analyze software is that used together they provide the ability to classify anomalies as being either TOI or non-TOI. Conventional DGM sensors (e.g., EM61-MK2) have very limited ability to discriminate between TOI and non-TOI. Other advanced EMI sensors (e.g., Berkeley UXO Discriminator, Man-Portable Vector) have also been successful in Strategic Environmental Research and Development Program (SERDP)- and ESTCP-funded classification demonstrations; however, they were not used during this live site demonstration.

The MetalMapper has a large sensor and bulky components required for its operation (windows computer, monitor, 12-volt batteries); therefore, a deployment vehicle is required during surveys. For this demonstration a diesel-powered tele-lifter was used for survey activities. The size and portability of the MetalMapper in the open field at SWPG became an issue because of heavy clay soils that were saturated from periodic heavy rains. These field conditions impacted all phases of field operations and likely would have had similar impact to other survey instrumentations.

Figure 2-1. Dynamic MetalMapper Deployment at SWPG



3. PERFORMANCE OBJECTIVES

The performance objectives for this demonstration are summarized in Table 3-1 and Table 3-2.

Table 3-1 lists the performance objectives for all field activities. These apply to all detection and classification work performed in RF-15. Table 3-2 lists the performance objectives for the advanced classification activities. These objectives apply to all similar work performed using RF-15 advanced classification data.

Table 3-1. Performance Objectives for Field Activities

Performance Objective	Metric	Success Criteria	Results
Repeatability of Instrument Verification Strip (IVS) measurements	Amplitude of EM anomaly Measured target locations	Adv. Sensors Survey: Down-track location ±25 cm Adv. Sensors Cued: Library match ≥90% using 3-criterion metric with equal weighting to the three criteria using first day's IVS inversion as the library item.	Pass – All IVS events achieved a detection offset of <25 cm for all seed items Pass – All IVS events achieved a ≥90% library match using an equally weighted 3-criterion match
Complete coverage of the demonstration site	Footprint coverage calculated using UX-Process Footprint Coverage Quality Control (QC) tool; excludes inaccessible areas.	>= 85% coverage at 0.75-m line spacing; and >= 98% coverage at 0.9-m line spacing	Pass – 99.8% coverage was achieved at a 0.75-m line spacing
Along-line measurement spacing	Point-to-point spacing from data set	98% < 15 cm along-line spacing	Pass – 99.6% of the along-line spacing was <15 cm
Detection of all TOI	Percent detected of TOI	100% of TOI detected within 40-cm halo of the surveyed location	Pass – 100% of TOI was detected within a 40-cm halo
Cued interrogation of anomalies	Instrument position	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	Fail – only 94% of the cued measurements were within the 40-cm metric

Table 3-2. Performance Objectives for Advanced Classification Activities

Performance Objective	Items	Metric	Success Criteria	Results
Correctly classify QC seeds and correctly classify native and population seed items	All seeds and all native TOI	Percent classified as TOI	100% classified as TOI	Pass – all TOI were properly classified
Correctly identify group	All TOI and all excavated non-TOI	Percent of TOI and excavated non-TOI grouped correctly	85% correctly grouped in the small, medium, and large groups	Pass – 97% were assigned to the correct group
Correct estimation of extrinsic target parameters	All excavated anomalies	Measured location and depth to center of mass of recovered items	X, Y < 15 cm (1 σ) Z < 10 cm (1 σ)	Fail – only 67% of X,Y < 15 cm of the actual measured location Fail – only 75% of Z <10 cm of the actual depth
Maximize correct classification of non-TOI	All non-TOI	Number of false alarms eliminated	Reduction of clutter digs by >50% while meeting all other demonstration objectives	Pass – 84% of non-TOI were correctly classified
Minimize number of anomalies that cannot be analyzed	All cued anomalies	Number of anomalies that must be classified as "Unable to Analyze"	Reliable target parameters can be estimated for > 95% of anomalies on each sensor anomaly list.	Pass – only 2% classified as "Cannot Analyze"

3.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

The reliability of the survey data depends on the proper functioning of the survey equipment. This objective concerns the twice-daily confirmation of sensor system performance.

3.1.1 Metric

The metrics for this objective are the down-track position of the maxima for the MetalMapper when used in dynamic survey mode, and the percent match of the inverted data to the library for the specific seed items when surveying in cued mode. These metrics are applied for each of the twice-daily surveys of the IVS.

3.1.2 Data Requirements

The IVS data were used to judge this objective. For cued surveys, the first day's IVS measurement over each Industry Standard Object (ISO) was used as the library basis for all future IVS comparisons during the project.

3.1.3 Success Criteria

This objective is considered a success for dynamic survey data if the down-track position of the anomaly is within 25 cm of the seed item's known location. The objective is considered to be met in cued mode if the library matches are equal to or greater than 90%.

3.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability of WESTON to completely survey the site and obtain valid MetalMapper.

3.2.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC tool.

3.2.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.2.3 Success Criteria

This objective is considered a success if the MetalMapper dynamic survey achieved at least 85% coverage at 0.75-m line spacing and 98% at 0.9-m line spacing calculated using the UX-Process Footprint Coverage QC tool.

3.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The reliability of the survey data depends on the measurement density. This objective concerns the ability of WESTON to acquire sufficiently dense measurements to obtain valid data.

3.3.1 Metric

The metric for this objective is the point-to-point distance as measured using UX-Process point-to-point distance tool.

3.3.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.3.3 Success Criteria

This objective is considered a success for dynamic MetalMapper surveys if 98% of the data have along-line spacing of 15 cm or less.

3.4 OBJECTIVE: DETECTION OF ALL TOI

Quality data should lead to a high probability of detecting the TOI at the site. This metric applies only to the detection phases of work and is specific to those items defined as detectable, which for this project is initially defined as peak signal 7 times site root mean square (RMS) noise.

3.4.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.4.2 Data Requirements

A target list was generated by WESTON and compared against the surveyed locations of the seed items.

3.4.3 Success Criteria

The objective is considered a success if 100% of the seeded items are detected within a 40-cm halo of their surveyed locations.

3.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.5.1 Metric

The metric for this objective is the percentage of anomalies that are within the acceptable distance from the center of the instrument to the actual target location during data collection.

3.5.2 Data Requirements

The location of the center of the MetalMapper array at each cued anomaly was compared against the measured locations of items recovered during intrusive investigations.

3.5.3 Success Criteria

The objective is considered a success if the center of the instrument is positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

3.6 OBJECTIVE: CORRECTLY CLASSIFY QC SEEDS AND CORRECTLY CLASSIFY NATIVE AND POPULATION SEED ITEMS

This metric applies to QC seeds, population seeds, and native TOI. Seed items are used to provide objective and quantitative measurement of the classification process and are used to supplement advanced classification objectives.

The seeds for this demonstration are small ISO80; medium ISO40; 20mm, 37mm, 40mm, 75mm, 90mm, and 105mm projectiles; and 81mm mortars. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all TOI.

3.6.1 Metric

The metrics for this objective are the percentage of TOI correctly identified on the TOI lists.

3.6.2 Data Requirements

Ranked anomaly lists, separated into TOI and non-TOI lists, were used to judge the success of this objective.

3.6.3 Success Criteria

The objective is considered to be met if 100% of the QC seeds, population seeds, and native TOI are placed on the TOI list.

3.7 OBJECTIVE: CORRECTLY IDENTIFY GROUP

The objective is to correctly assign each TOI and non-TOI to either the small group (small ISO80 and up to 40mm diameter), medium group (medium ISO40 and up to 81mm diameter), or large group (90mm and 105mm projectiles).

3.7.1 Metric

The metrics for this objective are the percentage of TOI and non-TOI correctly grouped in either the small, medium, or large groups.

3.7.2 Data Requirements

Anomalies grouped as small, medium, or large were used to judge the success of this objective. The data depended on the usability of the beta ($\beta 2$) and $\beta 3$ polarizability curves.

3.7.3 Success Criteria

The group assignment task is considered successful if 85% or more of the group designations are correct.

3.8 OBJECTIVE: CORRECT ESTIMATION OF EXTRINSIC TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis (data inversion). Successful classification is possible only if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.8.1 Metric

Accuracy of estimation of extrinsic target parameters is the metric for this objective.

3.8.2 Data Requirements

The predicted anomaly locations and depths were compared against the measured locations of items recovered during intrusive investigations.

3.8.3 Success Criteria

The objective is considered a success if the estimated X, Y locations are within 15 cm (1 σ) and the estimated depths (Z) are within 10 cm (1 σ).

3.9 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, was able to classify the targets with high accuracy. This objective concerns the component of the classification problem that involves false alarm reduction.

Because the number of clutter items that may resemble 20mm projectiles is unknown, the success metric for this objective (50%) is lower than that of most previous demonstrations, which typically use a metric of 65%.

3.9.1 Metric

The metric for this objective is the number of cued anomalies that can be correctly classified as non-TOI.

3.9.2 Data Requirements

WESTON prepared a prioritized non-TOI list from the cued anomaly list. Institute for Defense Analysis (IDA) personnel used their scoring algorithms to assess the results.

3.9.3 Success Criteria

The objective is considered a success if more than 50% of the non-TOI items can be correctly labeled as non-TOI while meeting the objectives or success criteria for TOI stated in Table 3-2.

3.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be placed in the dig category and will consequently reduce the effectiveness of the classification process.

3.10.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.10.2 Data Requirements

Anomalies for which parameters cannot be reliably estimated are assigned a Category 0 on the final ranked anomaly list.

3.10.3 Success Criteria

The objective is considered a success if reliable parameters can be estimated for > 95% of the anomalies on each sensor anomaly list.

4. SITE DESCRIPTION

The site description information presented in this section is taken from the Engineering Evaluation/Cost Analysis (EE/CA) [1 and 2]. More details can be obtained in the EE/CA and in the Archive Search Report [3]. The former SWPG is a 50,077-acre Formerly Used Defense Site located near Hope, Arkansas. The demonstration was conducted in a portion of RF-15.

4.1 SITE SELECTION

This site was chosen as the next in a series of sites for demonstration of the classification process. The first site in the series, former Camp Sibert in Alabama, had only one TOI and item "size" was an effective discriminant. A hillside range at the former Camp San Luis Obispo in California was selected for the second of these demonstrations because of the greater diversity of munitions, including 60mm, 81mm, and 4.2-inch mortars and 2.36-inch rockets. Three additional munitions types were discovered during the course of the demonstration. The third site chosen was the former Camp Butner in North Carolina. This site is contaminated with items as small as 37mm projectiles, adding yet another layer of complexity to the process. Additional sites, including the former SWPG, provide opportunities to demonstrate the capabilities and limitations of the classification process under a variety of site conditions.

The former SWPG was selected for demonstration because it was expected to contain a diversity of munitions in high concentrations. These features increase the site's complexity and are similar to conditions encountered on production sites. The final demonstration area had a clear sky view for global positioning system (GPS) systems.

4.2 BRIEF SITE HISTORY

In 1941, construction began on the Proving Ground. Actual testing began in January 1942. Items tested at the facility included 250-pound and 500-pound bombs; mines; 60mm and 81mm mortars; hand and rifle grenades; 20mm, 37mm, 40mm, 75mm, 76mm, 90mm, 105mm, and 155mm projectiles; and small rockets. Although a fair majority of the rounds tested were inert/ballast, fillers also included high explosives, white phosphorous, and smoke mixtures. No chemical material was tested.

Operations continued until September 1945. Upon closure, subsequent range clearances were performed for surface contamination, with Certificates of Clearance being issued in 1947 and 1948 delineating specific areas as "surface use only." In the early 1950s additional range clearances were performed by Army Corps of Engineers clearance teams, with a final Certificate of Clearance being issued 16 March 1954.

An EE/CA was performed in RF-15. Current land use in RF-15 is residential and agricultural.

4.3 MUNITIONS CONTAMINATION

The expected munitions at RF-15 are listed in Table 4-1, which were based on the information in the current conceptual site model for these recovery fields. The bolded items in the table identify munitions types recovered within the recovery fields during the EE/CA. The non-bolded items were recovered at nearby locations either during the EE/CA or removal actions and are reasonable to anticipate as potential munitions and explosives of concern (MEC) (in particular UXO) present in RF-15.

Table 4-1. Known and Suspected Munitions Types*

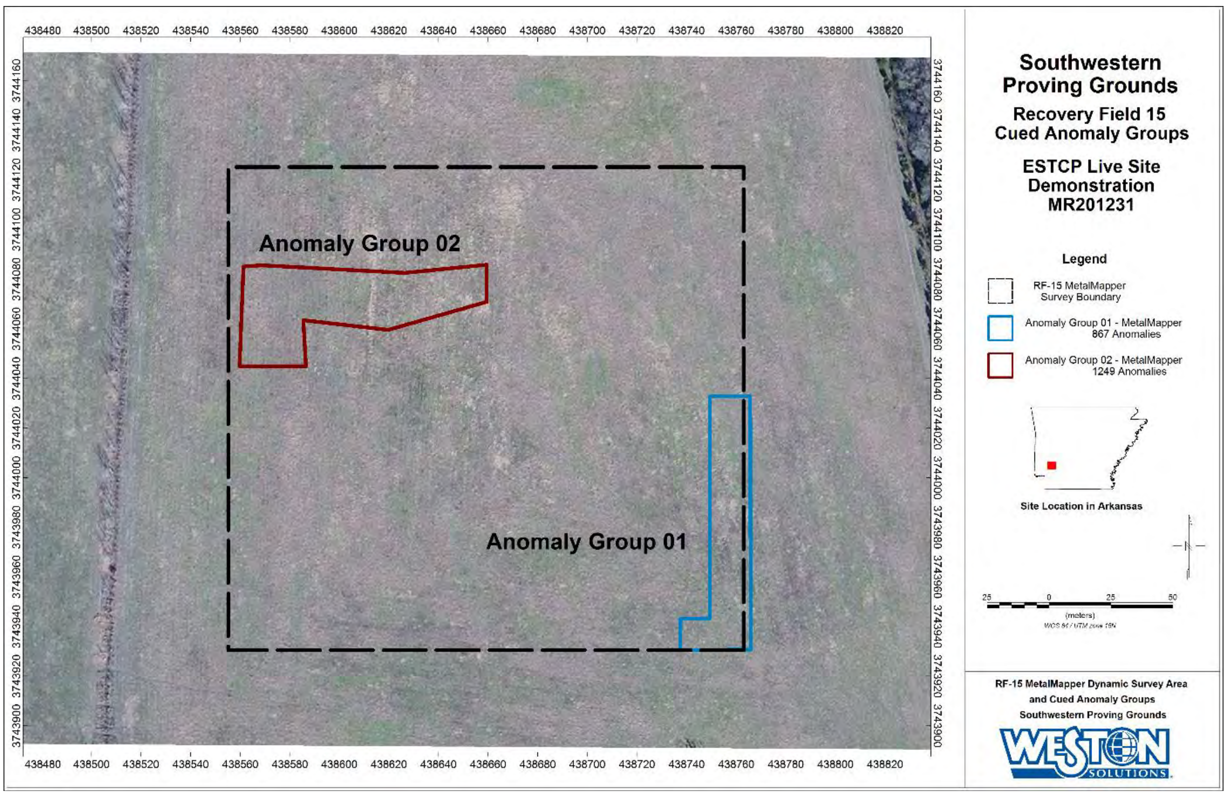
RF-15	**20mm**, 37mm, **40mm**, **57mm**, 75mm, **76mm**, 81mm mortar, **90mm**, 105mm, 155mm

* Bolded items were recovered within the RF during the EE/CA. Non-bolded items are suspected based on the current conceptual site model.

4.4 SITE CONFIGURATION

The demonstration site covers 10 acres within RF-15. The MetalMapper was used in dynamic mode to survey the 10-acre site with 100% coverage. Two subset investigation areas, Anomaly Group 1 and Anomaly Group 2, were selected for cued investigation. The demonstration site and anomaly groups are shown in Figure 4-1.

Figure 4-1. Recovery Field 15 Survey Area



5. TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program was to demonstrate a methodology for the use of classification in the munitions response process. The three key components of this methodology were collection of high-quality advanced sensor dynamic detection mapping data; selection of anomalous regions in those data; and subsequent cued interrogation and analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties; and the use of those parameters to construct a ranked anomaly list. Each of these components was handled separately in this program.

Dynamic data were processed, and anomalies were selected and subsequently cued. Individual cued data sets were processed using existing routines in UX-Analyze Advanced to extract target parameters. These parameters were passed to the classification routines that were used to produce ranked anomaly lists.

A total of 2,116 anomalies in RF-15 were selected for cued interrogation. As a result of time constraints and intrusive investigation results, 1,398 of those anomalies were intrusively investigated.

The primary objective of the demonstration was to assess the effectiveness of the classification process in separating TOI from high-confidence clutter.

5.2 SITE PREPARATION

5.2.1 Survey of Historical Records

Much of the historical information on the former SWPG was presented in the EE/CA report. This report is posted on the ESTCP ftp server and can be used for reference.

5.2.2 First-Order Navigation Points

Two first-order survey monuments were installed at the site. Their labels and coordinates are provided in Table 5-1.

Table 5-1. Geodetic Control Locations

ID	Latitude	Longitude	Elevation NAVD88 (m)	Northing (m)	Easting (m)
ESTCP1	N33º47’56.89499	W93º37’49.72688	103.855	3740063.731	441639.431
ESTCP2	N33º49’51.69395	W93º39’42.87732	79.057	3743617.714	438752.724

5.2.3 Initial EMI Survey

To assist in determining the location and boundary of the demonstration area, a wide-area EMI survey was performed by a third party using an EM61-MK2. Data were collected on parallel transects spaced 5m to 15m apart. Visual Sample Plan was used to calculate anomaly densities within RF-15. The boundaries of the demonstration area were positioned so that a broad range of anomaly densities would be captured within the demonstration area.

5.2.4 Surface Sweep

Prior to collecting DGM data, WESTON conducted a surface sweep within the demonstration area in RF-15 from April 8 to April 12, 2013. WESTON UXO technicians performed the surface sweep using Schonstedts to remove surface metal and any explosive hazards associated with potential MEC.

5.2.5 Seed the Site

WESTON installed 43 seeds within the demonstration area in accordance with the parameters laid out in the *ESTCP MR Live Site Demonstration Seeding Plan*. Each flagged location was swept with a Schonstedt to ensure a clean area for emplacement. A hole was dug and seeds were placed at the appropriate depth based on seed type, with larger items placed at greater depth. Physical characteristics of the seed were recorded on a whiteboard and placed alongside the excavated hole for a photograph (Figure 5-1). A Trimble R8 Real Time Kinematic (RTK) GPS was used to measure and record the location of each anomaly at depth.

Figure 5-1. Photograph of Seed Installation

5.2.6 Establish an IVS and Training Pit

An IVS and test pit area were established within a quiet area free of subsurface metal south of the demonstration site. The IVS was visited twice daily to verify proper sensor operation and functionality. An as-built schematic of the IVS is detailed in Figure 5-2. Details of seed items placed in the IVS are listed in Table 5-2.

Figure 5-2. Layout of the IVS Established at SWPG

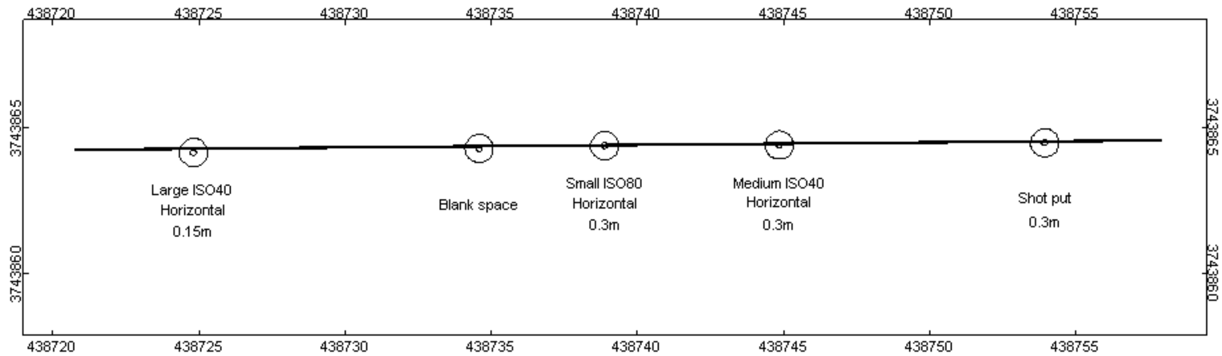


Table 5-2. Details of the Instrument Verification Strip

Item ID	Description	Design Easting (m)	Design Northing (m)	Depth (m)	Inclination	Azimuth (cw from N)
T-001	Shot put	438753.914	3743864.473	0.3	N/A	N/A
T-002	Medium ISO40	438744.843	3743864.394	0.3	Horizontal	Across Track
T-003	Small ISO80	438738.863	3743864.373	0.3	Horizontal	Across Track
T-004	Blank space	438734.57	3743864.28	N/A	N/A	N/A
T-005	Large ISO40	438724.804	3743864.139	0.15	Horizontal	Across Track

The IVS was used for daily function checks of the survey equipment. WESTON surveyed the strip twice daily, once each morning and evening of survey work. Through the monitoring of the responses and detected positions of the IVS seed items throughout the duration of the project, it was verified that equipment was functioning properly.

A test pit was established near the IVS at a quiet location free of subsurface metal and was used to measure the signatures of TOI expected to be present within the demonstration area. Measurements were performed for each test pit item at multiple depths and orientations. The test pit data collected are listed in Table 5-3.

Table 5-3. Test Pit Items and Orientations

Item ID	Depth (cm)	Orientation
Small ISO (sched 80)	2, 10, 20, 30	Horizontal
Medium ISO (sched 40)	12, 22, 25, 32, 59, 66	Horizontal, Vertical
20mm	6, 17, 27	Horizontal
37mm-MK1	15, 26	Horizontal
37mm projectile	15, 26	Horizontal
40mm projectile	16, 30, 35	Horizontal, Vertical (nose down)
57mm projectile (w/ rotating band)	12, 22, 29, 32, 67	Horizontal, Vertical (nose down)
57mm projectile (w/o rotating band)	12, 22, 29, 32, 67	Horizontal, Vertical (nose down)
60mm mortar	12, 15, 30, 35	Horizontal, Vertical (nose down)
75mm shrapnel (no fuze)	15, 34, 70, 74	Horizontal, 45 degree (nose down)
81mm mortar	13, 34, 70	Horizontal, 45 degree (nose down), Vertical (nose down)
90mm projectile	34, 69, 74	Horizontal, Vertical (nose down)
105mm projectile	32, 67	Horizontal, Vertical (nose down)

5.3 DATA COLLECTION

5.3.1 Dynamic Data Collection

WESTON performed dynamic detection surveys within the RF-15 demonstration areas from April 18 to 29, 2013. Dynamic detection data were collected from a total of 11.23 acres using the MetalMapper, equating to an average of 1.4 acres per day. Prior to the survey, a map of projected survey lines in RF-15 was loaded into EM3DAcquire to use for navigation. As each survey line is collected, EM3DAcquire displays a colored swath the width of the sensor footprint showing the operator where data have been acquired. Data gaps were typically identified in the field and re-collected the same day.

The dynamic detection surveys were performed with the MetalMapper sensor seated within a sled, which was attached to the front mount-plate of a diesel-powered tele-lifter (see Figure 5-3). The tele-lifter allowed the MetalMapper to be raised up and down and easily maneuvered side to side. A monitor mounted within the vehicle displayed real-time navigation and sensor information, and allowed the operator to collect data in both dynamic and cued survey modes. EM3DAcquire was used during this demonstration to control data acquisition parameters, storage of data, and navigation.

Figure 5-3. MetalMapper Setup for Cued Data Collection at SWPG

A Trimble R8 RTK GPS was used for navigation. The rover head was mounted directly over the center of the MetalMapper transmit coil. An inertial measurement unit (IMU) was installed directly below the rover head to capture pitch, roll, and yaw of the sensor.

Dynamic MetalMapper survey data were acquired with a design line spacing of 0.60 m. Data were initially collected with a 0.75-m line spacing; however, it was observed after the first day of dynamic survey that a 0.75-m spacing was resulting in data gaps because of the soft ground and rutting that was present in the field, so a tighter line spacing of 0.6 m was used to achieve full coverage.

5.3.2 Dynamic Data Processing

The raw binary MetalMapper *.TEM files were converted to ASCII *.CSV files using Geometrics EM3D data conversion software. Converted data were then imported into Geosoft Oasis montaj for processing and analysis using scripted import routines. Upon import, raw data were inspected to ensure that sensor data were valid and that peripheral input data streams (GPS, IMU) were present. Dynamic detection data were imported, processed, and validated on a daily basis.

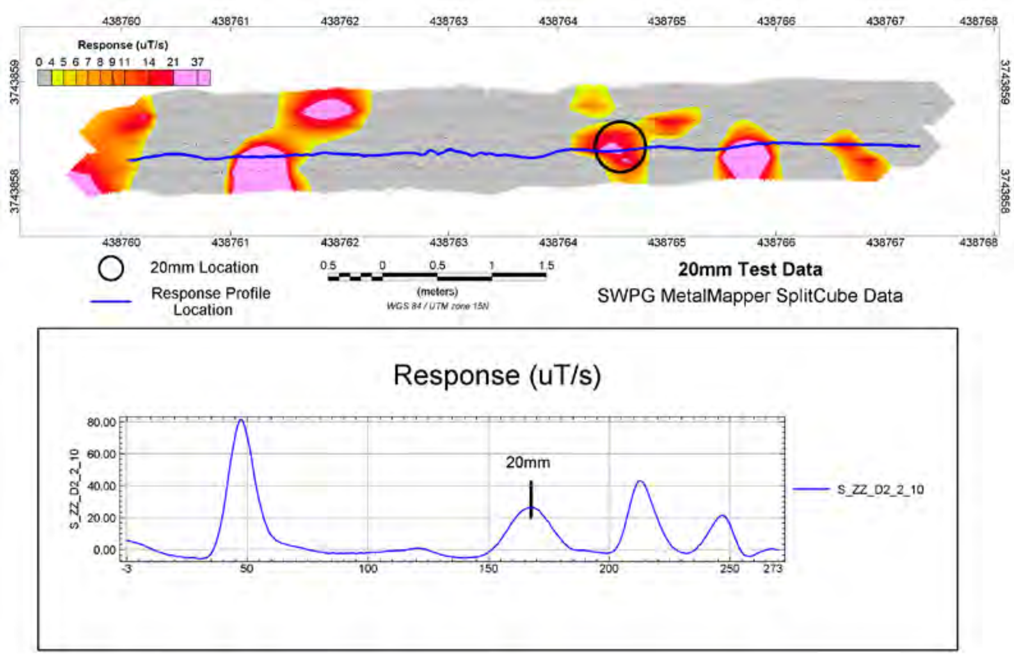
The individual sensors within the MetalMapper dynamic detection data were then located using the UX-Process "Sensor Offset Correction" GX and exported to a separately located database, with each sensor assigned a unique version number per line (e.g. Line 1, sensor 1 equates to Line 1.1, Line 1, sensor 2 equates to Line 1.2). Sensor offsets were calculated in reference to the RTK GPS position at the center of the array, with IMU data used to adjust for pitch, roll, and yaw in the sensor array. For this demonstration, the two outermost receiver cubes (cubes 1 and 7) were not used in the dynamic detection data analysis because of significantly lower responses resulting from their position at the outer edge of the transmit coil. Data analysis and anomaly selection were performed on the z-axis component of the five innermost receiver cubes (cubes 2 to 6).

The dynamic detection data were then levelled using a de-median background removal filter. Once the daily data had been imported, validated, and levelled, the data were then merged into a master site database containing all dynamic data collected to date. Once data collection was complete, the master database was used for gridding, anomaly selection, and analysis.

5.3.3 Anomaly Selection

Anomalies were selected from processed MetalMapper dynamic detection data using the Geosoft Blakely grid peak detection algorithm. To determine a suitable anomaly selection threshold, dynamic test data were acquired over a 20mm projectile buried at the target detection depth of 15 cm. An example of the 20mm test strip data collected is shown in Figure 5-4.

Figure 5-4. 20mm Dynamic Data Test Strip Response Results



The stacked response of the third through eleventh time gates was used for target selection. The response amplitude of a horizontal 20mm anomaly at 15-cm depth was determined to be approximately 26.50 microtesla (µT). Background noise analyses were performed on anomaly free locations within the test strip data, and RMS noise was approximately 2.57 µT for the stacked response channel (stacked response of third through eleventh time gates). A target conservative threshold of 17.99 µT (7 times the RMS noise level) was chosen to allow the detection of a 20mm projectile at a depth of 15 cm below ground surface.

5.3.4 Cued Data Collection

WESTON performed cued data collection from May 13 to 30, 2013, on 2,116 targets that were based on anomaly lists approved by the IDA, averaging 281 cued locations each day for 8 field days. Cued targets locations were loaded into EM3DAcquire, which was used for navigation as well as data storage. The operator positioned the MetalMapper within 40 cm of the center of target location and collected a cued shot for a 60-second period over the anomaly. To account for changing soil conditions, background shots were collected once an hour in a quiet area identified in the dynamic data. The cued data were reviewed each evening, and cued locations that fell outside the 40-cm offset metric were re-collected as necessary.

5.3.5 Cued Data Processing

Cued data processing was performed using the UX-Analyze Advanced extension in Geosoft Oasis montaj. Cued background data were imported and qualitatively verified, with any outliers removed from the background dataset. After background data had been verified, cued anomaly data were imported, verified for completeness, and background corrected using the cued background data spatially and temporally closest to the cued anomaly location.

Inversions were performed on each cued anomaly using both single-source and multi-source models to extract target parameters, fit coherence, and predicted locations and depths for each model. The primary parameters used for classification were the three polarizabilities (β_1, β_2, and β_3) calculated for each single-source and multi-source modeled result.

Daily quality control was performed on the cued anomaly data in which the cued location (Real Time Kinematic [RTK] GPS location), modeled locations, and flagged locations were compared to verify that the center of the MetalMapper array was within the 40-cm radius of the anomaly source. Targets outside the 40-cm metric were identified and re-collected as necessary.

After the individual, inverted locations from the cued sensors were complete, the data were combined into a master dig list for each anomaly group. These Master Dig Lists contained one entry for each predicted anomaly from the inversions of the cued data.

5.3.6 Data Handling

WESTON provided dynamic detection data to the ESTCP Program Office for archiving in raw instrument *.TEM and converted ASCII *.CSV formats, as well as located, processed data in Geosoft database (*.gdb) format. Cued data were provided in raw instrument files *.TEM format, uncorrected ASCII *.CSV files, and background corrected data in Geosoft *.GDB format

5.4 INTRUSIVE ACTIVITY AND PROCEDURES

WESTON performed intrusive operations on RF-15 Areas 1 and 2 from September 30 through October 28. A seven-person team, including the Senior Unexploded Ordnance Supervisor (SUXOS) and Unexploded Ordnance Quality Control Specialist/Safety Officer (UXOQCS/SO), executed 1,398 intrusive investigations over 17 field days, averaging 82 digs per day. The dig production rates were largely influenced by the high density of small frag and by the heavy clay soils.

All targets were investigated and documented according to the procedures outlined in the *Intrusive Investigation Data Collection Instructions* [4], including the following:

- **Perform reacquisition of targets** – Targets selected for intrusive investigation were uploaded to a Trimble RTK R8 system and reacquired using polyvinyl chloride (PVC) pin flags.

- **Dig a “plug” around the flag** – To reduce the impact to the survey area, which is located in a farm field, a soil plug was dug around each pin flag, to be returned once the item had been removed from the hole.
- **Identify recovered item** – All items recovered were inspected by the UXOSO and SUXOS to ensure that all items were properly identified by the UXO team and all items were certified and verified as material documented as safe (MDAS).
- **Enter data to personal data assistant (PDA)/whiteboard and take photograph** – Field observations of each recovered item were entered into PDAs. The exact location of the item in situ was recorded using the Trimble RTK. Key information was written onto a whiteboard and a photograph was taken with the item (see Figure 5-5).
- **Bag and label item** – All recovered items were placed in plastic zippered bags and labeled.
- **Perform QC inspection with EM-61 handheld** – Before an excavation was declared clear, the hole was inspected by the UXOQCS using a handheld EM-61 MKII.
- **Backfill hole** – Once the excavation was declared clear, the hole was backfilled and the soil plug returned.

One item encountered during intrusive operations required explosive demolition. A 105mm projectile was encountered at 1 m depth at target SW-11175. The item was inspected by the SUXOS and UXOSO, and its filler and configuration could not be verified. WESTON personnel set up demolition operations on October 23, 2013. After demolition operations were complete, the round was determined to be a fuzed practice 105mm projectile.

5.5 INTRUSIVE INVESTIGATION RESULTS

During the course of intrusive operations, 1,398 targets were investigated and 2,013 items were recovered. This included 16 seeds that fell within the boundary of Areas 1 and 2. The majority of the munitions debris (MD) recovered consisted of unidentifiable munitions fragments. Cultural debris items recovered were largely pieces of farming equipment. Table 5-4 summarizes the results of the intrusive operations in RF-15.

Table 5-4. RF-15 Intrusive Summary

Area	Item Type	Items Recovered
Area 1	Cultural Debris	16
	Munitions Debris	954
	No Contact	4
	Seed	9
	MEC	1
Area 2	Cultural Debris	8
	Munitions Debris	1,019
	No Contact	7
	Seed	7
	MEC	0
RF-15 Areas 1 and Area 2 (Total)	Cultural Debris	24
	Munitions Debris	1,973
	No Contact	11
	Seed	16
	MEC	1

6. CLASSIFICATION

Classification for cued anomaly data collected at SWPG was based primarily on the library match statistic generated in UX-Analyze Advanced during library matching of modeled results against the demonstration site TOI library of expected munitions and TOI. The multi-criteria method (introduced in UX-Analyze v8.2) was used, in which the library match statistic of four combinations of beta (β) criteria weights were calculated and then averaged to create a decision statistic. Library match statistic combinations used to calculate the decision statistic are listed in Table 6-1.

Table 6-1. Multi-Criteria Library Match Statistic Combinations

Library Match Statistic Combination	Criteria Weighting		
	β1	β2	β3
LmStat_111	1	1	1
LmStat_110	1	1	0
LmStat_011	0	1	1
LmStat_100	1	0	0

In addition to the matching of βs to a library of known TOI, self-matching was also performed in which βs for each modeled result were compared to the βs of all other modeled results to identify clusters of similar items that may not be present in the TOI library. Items identified in self-match clusters or from clusters identified in feature space (size vs decay plot) were then evaluated to be included in a training data request. Cluster analysis resulted in a training data request for 18 digs. The data received from the training digs were used to further refine the decision metric thresholds in the ranked anomaly list. Clutter items from the training dig results were also added to the clutter library to be used in the final classification process.

The following parameters were used in the ordering of the ranked anomaly list:

- Decision statistic
- Signal amplitude
- Fit depth
- Size and decay
- Array to fit location offset
- Fit coherence
- Library match statistic to clutter library

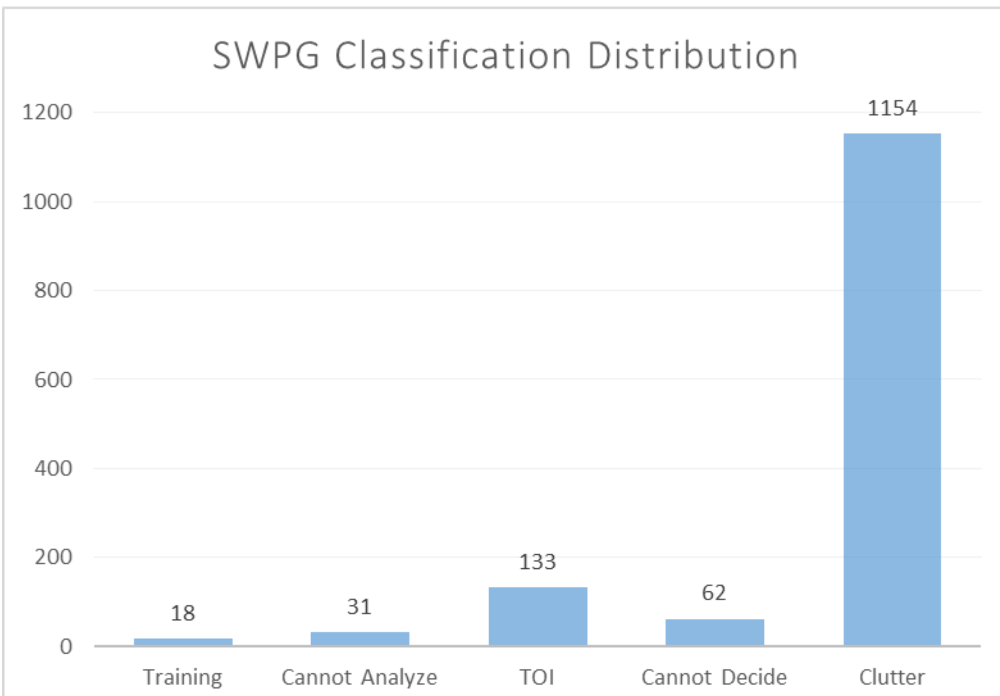
From these parameters, each single and multi-source modeled result was placed into one of four categories 0 to 3, with the best ranked modeled result from each cued anomaly being passed onto to a final ranked list based on the parameters outlined in Table 6-2.

Table 6-2. Ranked List of Parameters

Ranked List Category	Category Description	Criteria
Category -1	Training Digs	Training digs requested by analyst
Category 0	Cannot Analyze	Fit coherence < 0.8
Category 1	Likely TOI	Decision statistic >0.90
Category 2	Cannot Decide	Decision statistic >0.85 but <0.90
Category 3	Clutter	Decision statistic <0.85

The ranked anomaly list derived from this classification scheme resulted in the classification distribution displayed in Figure 6-1.

Figure 6-1. Southwestern Proving Ground Classification Distribution



WESTON submitted the ranked anomaly list to the ESTCP Program Office for scoring by the IDA. The intrusive results, including detailed anomaly description, photo documentation, and a receiver operating characteristic (ROC) curve indicating the percentage of TOI identified for the 226 anomalies placed on the dig list (Categories 0, 1, and 2), were supplied to WESTON for review.

7. PERFORMANCE ASSESSMENT

The performance objectives for this demonstration and the corresponding results are summarized in Table 3-1 and Table 3-2.

Table 3-1 lists the performance objectives for the field activities. These apply to the detection and classification work performed at RF-15. Table 3-2 lists the performance objectives for the advanced classification activities. These apply to the similar work performed using RF-15 advanced classification data.

7.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

7.1.1 Dynamic IVS

This objective involved the repeatability of the detection location of seed items in dynamic IVS data collection. Seed item offsets for each dynamic IVS data collection event were tracked throughout the life of the dynamic portion of the project. This objective was considered to be met if all locations of seed items as detected in the dynamic IVS data were offset <25 cm from the actual surveyed location. Results for dynamic detection IVS surveys are detailed in Table 7-1.

Table 7-1. IVS Seed Item Detection Results

Seed Item	Minimum Offset (cm)	Maximum Offset (cm)	Average Offset (cm)
Shotput	3.00	12.00	5.00
Medium ISO40	4.00	14.00	7.00
Small ISO80	5.00	17.00	10.00
Large ISO40	1.00	14.00	7.00

The detected locations of the IVS seed items were all within 25 cm of the actual surveyed locations. The greatest variation occurred in the Small ISO80, which had a maximum detected offset of 17 cm from the actual location.

7.1.2 Cued IVS

This objective involved the repeatability of classification of IVS seed items during cued data collection. Seed item library match statistics for each cued IVS data collection event were tracked throughout the life of the cued portion of the project. This objective was considered to be met if the library match statistic for all seed items cued in the IVS was ≥90% when using a three-criterion metric with equal weighting to the three criteria when measured against the first day's cued IVS. Results for cued IVS surveys are detailed in Table 7-2.

Table 7-2. IVS Library Match Results

Seed Item	Minimum Library Match Statistic	Average Library Match Statistic
Shotput	0.969	0.993
Medium ISO40	0.926	0.981
Small ISO80	0.982	0.994
Large ISO40	0.999	0.999

This performance objective was met, as the library match statistic of the inverted data to the IVS seed item library were all >90% during the duration of the cued survey.

7.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

This objective measured the effectiveness of the dynamic detection survey as a function of the amount of coverage of the demonstration area by the MetalMapper sensor. This objective was considered to be met if the dynamic detection survey achieved 85% coverage of the site at a 0.75-m lane spacing, and 98% of the site at 0.90m lane spacing.

The UX-Process Footprint Coverage QC tool was used to analyze the georeferenced positions of the center of the MetalMapper sensor array. Data were collected at a 0.60-m lane spacing to eliminate gaps caused by ruts and rough terrain. This objective was met because 99.8% of the site was covered at a 0.75-m lane spacing.

7.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

This objective evaluated the along-line data density, or sample separation, of the MetalMapper dynamic detection dataset acquired at RF-15. The metric for this objective was the point-to-point distance as measured using UX-Process Sample Separation utility. This objective was considered to be met if 98% of the data had an along-line spacing of 15 cm or less.

The UX-Process Sample Separation tool was used to analyze the along-line spacing of the georeferenced data positions of the MetalMapper sensor array. This objective was met because 99.6% of the data had a sample separation of 15 cm or less.

7.4 OBJECTIVE: DETECTION OF ALL TOI

This objective evaluated the dynamic detection capabilities of the MetalMapper array. The metric for this objective was considered to be met if 100% of native and non-native TOI were detected within a 40-cm halo of their recorded locations.

This objective was met because all TOI were successfully detected within 40 cm of the recorded locations. TOI included 43 seed items (non-native TOI) installed by WESTON prior to the dynamic detection survey, as well as 1 MEC item (native TOI). TOI detection results are detailed in Table 7-3.

Table 7-3. TOI Detection Results

Seed ID	Seed Type	Seed Offset (cm)
W-001	105mm Proj	11.00
W-002	20mm	11.00
W-003	Medium ISO	5.00
W-004	37mm	8.00
W-005	37mm	19.00
W-006	Medium ISO	13.00
W-007	37mm	8.00
W-008	Small ISO	6.00
W-009	37mm	9.00
W-010	37mm	8.00
W-011	75mm	4.00
W-012	Small ISO	11.00
W-013	Small ISO	8.00
W-014	Medium ISO	7.00
W-015	Small ISO	17.00
W-016	Medium ISO	17.00
W-017	37mm	8.00
W-018	81mm	16.00
W-019	37mm	9.00
W-020	37mm	10.00
W-021	37mm	13.00
W-022	37mm	12.00
W-023	75mm	11.00
W-024	Medium ISO	30.00
W-025	Small ISO	14.00
W-026	Small ISO	15.00
W-027	37mm	8.00
W-028	Medium ISO	5.00
W-029	37mm	16.00
W-030	75mm	5.00
W-031	Medium ISO	9.00
W-032	37mm	4.00
W-033	Small ISO	4.00

Table 7-3. TOI Detection Results (Continued)

Seed ID	Seed Type	Seed Offset (cm)
W-034	Medium ISO	3.00
W-035	Small ISO	13.00
W-036	37mm	15.00
W-037	Small ISO	7.00
W-038	Small ISO	4.00
W-039	Medium ISO	4.00
W-040	37mm	4.00
W-041	Medium ISO	3.00
W-042	90mm	5.00
W-043	Small ISO	26.00
105mm (MEC)	105mm w M557 Fuze	16.00

7.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

This objective evaluated the positioning of the instrument during data collection in relation to the actual anomaly location. The metric for this objective was considered to be met if the center of the instrument was positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

To evaluate this objective, the offset between the center of the MetalMapper array and the surveyed location of each recovered item was calculated. Of the 1,398 cued measurements that were intrusively investigated, 1,301 were within the 40-cm offset metric, 86 were outside of 40 cm. The remaining 11 reacquired anomalies were determined to be no-contacts and were removed from this evaluation. This objective was not achieved because only 94% of the cued measurements were within the 40-cm offset.

7.6 OBJECTIVE: CORRECTLY CLASSIFY QC SEEDS AND CORRECTLY CLASSIFY NATIVE AND POPULATION SEED ITEMS

This objective evaluated the effectiveness of the advanced classification process to properly classify TOI present within the survey area. The objective was considered to be met if 100% of the QC seeds, population seeds, and native TOI were placed on the TOI list.

A ranked anomaly list was submitted to the ESTCP Program Office for evaluation. This objective was met because all TOI were properly classified as Category 1 digs (likely TOI). This listing included one 105mm projectile (MEC) recovered in Anomaly Group 1.

7.7 OBJECTIVE: CORRECTLY IDENTIFY GROUP

This objective evaluated the effectiveness of the advanced classification process to properly assign each excavated TOI and non-TOI into the small, medium, or large grouping. The objective was considered to be met if 85% of the anomalies placed on the dig list were properly grouped.

Dig results for the ranked anomaly list submitted to the ESTCP Program Office were analyzed to verify size groupings. Of the 195 anomalies placed in the dig list, 190 were assigned to the correct size group, and 5 were assigned an incorrect group. This objective was met because 97% of the anomalies were correctly classified.

7.8 OBJECTIVE: CORRECT ESTIMATION OF EXTRINSIC TARGET PARAMETERS

This objective evaluated the accuracy of the target parameters that are estimated during the data inversion process by comparing the predicted extrinsic target parameters to the measured results recorded during the intrusive investigation. This objective was considered to be met if the estimated X and Y locations were within 15 cm and the estimated depths were within 10 cm.

This objective was not met because only 67% of the predicted locations were within 15 cm of the actual measured location, and only 75% of the predicted depths were within 10 cm of the actual depths.

The high percentage of item locations that were not predicted correctly is most likely as a result of the quantity of frag that was encountered within the survey area. Approximately 97% of the digs resulted in small pieces of frag that were either too numerous or too small to model well, thus yielding poor fit locations.

7.9 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This objective concerns the component of the classification problem that involves false alarm reduction. The metric for this objective is the number of cued anomalies that can be correctly classified as non-TOI. The objective was considered to be met if more than 50% of the non-TOI items were correctly labeled as non-TOI.

Dig results for the initial ranked anomaly list submitted to the ESTCP Program Office were used to assess the number of non-TOI that were correctly classified. Results are detailed in Table 7-4.

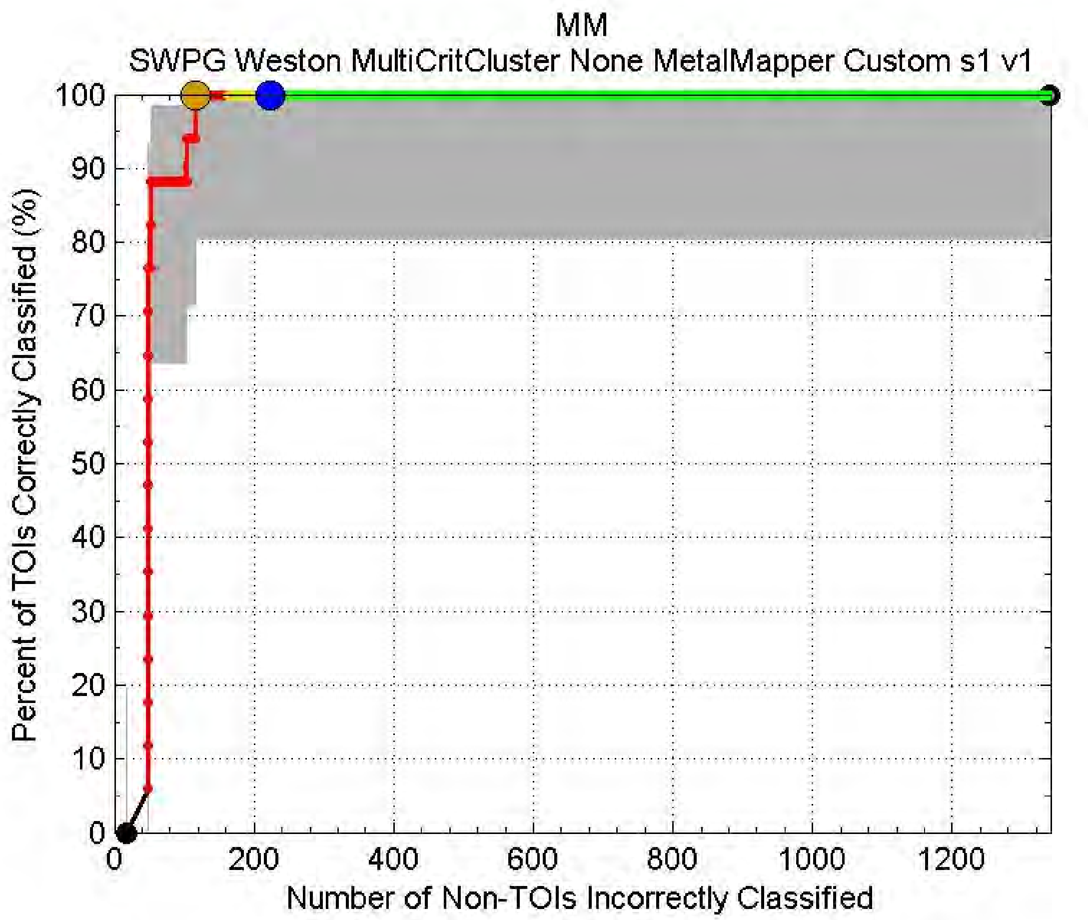
Table 7-4. Predicted vs. Actual Classification Results

	Categorized TOI	Categorized Non-TOI
Predicted	244	1,154
Actual	17	1,381
% Correctly Classified	100%	84%

This objective was met because 84% of non-TOI were correctly classified. In this classification scenario, 100% of TOI were correctly classified while achieving a false positive rate of only 15%.

An ROC curve generated from the dig results of the submitted ranked anomaly list is shown in Figure 7-1.

Figure 7-1. SWPG Final ROC Curve



7.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

This objective evaluated how well the modeled results of the inversion process correlated to the observed data. A fit coherence metric is calculated for each model during data inversion, and is used as the basis for determining whether reliable parameters could be estimated from the data. The objective was considered to be met if reliable parameters could be estimated for > 95% of the anomalies on each sensor anomaly list.

Modeled results with a fit coherence of less than 0.8 were placed in the 'cannot analyze' category. This objective was met because 98% of the cued data collected inverted with a fit coherence greater than 0.8.

8. COST BENEFIT ANALYSIS

The cost assessment for the SWPG demonstration includes a summary list of the project costs and potential savings from the classification process.

8.1 COST MODEL

The costs for the SWPG field demonstration included the seeding, MetalMapper surveys, data processing, and intrusive operations. These costs are summarized in Table 8-1.

Table 8-1. Details of Project Costs

Phase of Work	Elements of Work	Estimated Costs
Site Setup	Site prep, surface sweep, seeding, IVS installation.	$81,109
Dynamic Detection Survey	Includes effort for field data collection and processing/ anomaly selection	$52,241
Cued Survey	Equipment	$13,500
	Cued data collection	$34,583
	Processing and classification	$22,730
	Total cost per target for cued survey	$33.46 per target for 2,116 targets
Intrusive Investigation	Intrusive investigation of 1,398 anomalies, reacquire, demo operations, and related costs.	$195,860
	Total cost per target to intrusively investigate.	$140.10 per target for 1,398 targets

8.2 COST DRIVERS

The analysis compares the costs of the cued survey and classification process to intrusively investigating all anomalies classified as non-TOI. During the SWPG demonstration, 2,116 targets were surveyed in cued mode with MetalMapper. Based on the information listed in Table 8-1, the cost for the cued survey and classification was $33.46 per target. Of these 2,116, a total of 1,398 were intrusively investigated at a cost of $140.10 per target.

WESTON considers the costs incurred for both the cued survey and intrusive investigation an overestimation of the actual costs that would be necessary for future projects because these costs included equipment delivery delays and a lengthy setup process. When the MetalMapper was set up and fully functional, more than 300 targets could be cued in a single day. However, the implementation issues mentioned above (which are detailed in Section 9 of this report) resulted in an average collection of 281 targets per day at SWPG. For the intrusive phase, an average of 81 targets were investigated each day. Although some factors were favorable to this phase, such as the proximity of the targets, WESTON believes that at least 100 targets could be investigated each day. Some of the factors that affected the number of targets that were investigated each day include a high concentration of frag pits; significant detail in field data recording (for example, bagging and labeling each piece of frag, which would not be expected on a typical production project); a low picking threshold based on a 20mm projectile; and heavy clays, which made digging cumbersome.

8.3 COST BENEFIT

For SWPG, cued surveys and processing were performed for $33.46 per target, and intrusive investigation was performed for $140.10 per target. The classification process eliminated 83% of anomalies from the intrusive investigation, yielding a potential cost savings on this project of $112,284.00, based on the following factors:

- 1,398 anomalies at $140.10/anomaly for intrusive investigation equals a cost of $195,860.00.
- Reduction of 1,154 anomalies equals a reduction of $161,675 in excavation costs.
- MetalMapper cost for cued survey and classification of 1,398 anomalies at $33.46/anomaly equals a cost of $46,777.
- Total cost savings under this scenario equals $80,962.

9. IMPLEMENTATION ISSUES

Several implementation issues arose during the demonstration at SWPG, including the following:

- Delivery of the equipment was delayed. Because of the size of the MetalMapper, the instrument cannot be shipped by small package handlers. A large freight shipper must be used to handle the multiple pallets, and delivery dates are not always firm. The instrument arrived 2 days later than originally scheduled.
- Initial setup of the equipment took longer than anticipated. Representatives from Geometrics were on-site at SWPG to assist in the equipment setup; however, the unit had come from another project site and had not been checked thoroughly before being sent to SWPG. Several components were damaged or broken, and others were missing altogether. It had been expected that the equipment would take 1 to 2 days to set up. Instead, it took a full week for all equipment to become operational.
- The MetalMapper had to be transferred to a new sled. The MetalMapper arrived at SWPG with two sleds, the original first generation model that was shipped with the MetalMapper, and a new prototype model that had been recently fabricated and shipped by Geometrics. The instrument was set up on the original first generation sled platform because the mount bracket adapter for the newly fabricated model was missing. The old model sled was used throughout the dynamic phase of the MetalMapper survey. The older sled arrived with some structural damage to the bottom. As the survey progressed, the damaged worsened. Once the dynamic survey was completed, the MetalMapper had to be disassembled and reassembled onto the new sled. Because of damaged cables and the difficulty assembling the new platform, 2 days were spent transferring the equipment.

Minor setbacks also occurred during the project, such as software malfunctions, broken cables caused by cattle, and site accessibility issues because of heavy rains causing flooded site conditions. These types of setbacks are typical of any site and should be expected when planning field operations.

WESTON did discuss some suggested improvements to the system with Geometrics once survey operations were completed. Some of the topics included the following:

- **Simplify the cables** – One of the more time-consuming aspects of dealing with the MetalMapper is cable management. Each of the receivers and transmitters needs to be individually attached and secured. WESTON suggested that the cables be reduced to a single “transmitter” cable and a single “receiver” cable.
- **Weatherproof the system** – Limited protection of cables and electronics is built into the MetalMapper system. The computer sits facing up, with no shield to protect it from rain/debris/dust. Most of the cables do not have any additional sheathing beyond the manufacturing minimum, making them prone to pinches and pulls.
- **Structural improvement** – Several components of the MetalMapper require structural improvements. The GPS needs to be redesigned for additional stability and less maintenance (replacing screws/nuts that are consistently coming loose). The cushions used for vibration dampening need to better adhere to the MetalMapper or be integrated into the instrument design. The basket that holds the computer should be adjusted in size so that it

actually holds the computer. Currently, a combination of duct tape and come-along straps is used to secure the computer in place on the sled.

- **Tow vs push sled design** – The MetalMapper sled is currently constructed to be “pushed” during survey. For the cued investigation, this setup is ideal because it allows the user greater control and visibility when moving the sensor into a specific location. For the dynamic survey, a towed sled might be a better option, depending on the terrain. The installation of a ball-hitch on the sled would allow the user to have a choice in the field and potentially increase the versatility of the instrument.
- **Other modifications** – Other modifications discussed included a touchscreen interface for data collection, altering the color schemes of the software for greater visibility, and altering data-file nomenclature for easier data management.

10. REFERENCES

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Appendix A: Points of Contact

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